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WEIGHT AND POLARIZATION CHANGES OF PUERTO RICAN RAW SUGAR IN STORAGE AND SHIPMENT

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PREFACE

This study of changes in the weight and polarization of raw sugar shipped to United States mainland ports was undertaken at the request of the Puerto Rican sugar industry. It is part of a broad program of research designed to reduce marketing costs and increase efficiency in the marketing of farm products.

Recently, producers of raw sugar in Puerto Rico have reduced certain losses by shipping increasing quantities of their product in bulk rather than in bags. However, losses in storage still influence producers' returns. The findings of this study have application to the storage and shipment of raw cane sugar produced in continental United States, and to the storage of large quantities of imported bagged raw sugar.

The cooperation and assistance of the officers and members of the Association of Sugar Producers of Puerto Rico is appreciated.

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March 1958

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SUMMARY AND CONCLUSIONS

Losses of weight and polarization in bagged raw sugar during storage and shipment between Puerto Rican mills and United States mainland ports amount to approximately a million dollars a year. This estimate is based on data obtained from mills on shipments made in 1953, 1954, and 1955. The weight losses reported by these mills amounted to 0.59, 0.73, and 0.83 percent in 1953, 1954, and 1955, respectively. The polarization losses amounted to 0.43, 0.29, and 0.44 degree in the 3 respective years.

The weight of bulk raw sugar before it was stored was not available; therefore, it was not possible to measure the losses in bulk sugar during storage. Losses during shipping amounted to 0.28, 0.27, and 0.26 percent in 1953, 1954, and 1955, respectively. These losses were largely compensated by polarization gains of 0.12, 0.20, and 0.18 degree in the 3 years. No relationship was found between weight losses and polarization gains in bulk sugar, or between these changes and month of shipment. Greater weight losses were found in bagged sugar than in bulk sugar because of losses during storage, different methods of weighing, and spillage from bags.

Among mills there were considerable variations in losses of weight and polarization in bagged raw sugar. The weight losses ranged from 0.26 to 0.99 percent and the polarization losses ranged from 0.10° to 0.88°. Smaller variations were noted also from year to year for individual mills. The mills with the largest weight losses tended to have smaller polarization losses. This indicates that some of the weight losses were caused by moisture losses and did not contribute to a loss in value. In bagged sugar, a moisture loss would cause a polarization gain; therefore, the polarization losses would be somewhat greater than the data showed, if the losses were computed from the theoretical gain in polarization that would result from a moisture loss.

Both actual and 96°-equivalent weight losses in bagged raw sugar were greater in northern than in southern mainland ports. Methods of weighing in some northern ports would account for only a part of this difference. Polarization losses varied somewhat between ports but were not consistently greater or smaller in northern or southern ports.

About the same weight losses were shown on sugar stored until November and December, but during and after this 2 months' period they increased sharply. In the early part of the production season, January and February, the weight losses on shipments were high, but these shipments were a rather small part of the year's total. In November and December the losses increased to about the same level as they had been in January and February. The weight losses on shipments of carryover sugar (sugar marketed in January and February following the year it was produced) were greater than on shipments made during any other period of the year.

Polarization changes took place fairly soon after the sugar was produced. The polarization losses increased during the production season from January to June, and increased sharply during July and August. Thereafter, they dropped slightly during the rest of the year.

There was a loss of actual sugar content throughout the storage period. The losses of 96°-equivalent sugar increased from March and April to the end of the year. The losses on shipments made in January and February of the year following production were slightly less than on shipments made during the preceding November and December.

Losses of weight in bagged raw sugar may be attributed to loss of moisture, breakage of bags, and methods of weighing at some ports. Losses of weight in bulk sugar are negligible. Losses of polarization may be attributed to changes of moisture content, deterioration in storage and shipment, inaccurate sampling, or failure to adjust polarization at mill laboratories to allow for the temperature of 20° C. in laboratories at mainland ports.

The rapid shift from bagged to bulk raw sugar for shipments from Puerto Rican mills has eliminated or reduced the loss from such sources as bag breakage and methods of weighing. Further study is necessary to determine the extent of the storage losses of raw sugar stored in bulk.

INTRODUCTION

Sugar is the principal commodity exported from Puerto Rico. More than a million tons, representing 90 to 95 percent of the total production of the island, are shipped to continental United States each year. The mainland United States receives about one-eighth of its sugar requirements from Puerto Rico. Approximately 90 percent of the total shipments to mainland ports from this source is in the form of raw sugar.

This raw sugar is sold to mainland refiners on the basis of the weight and polarization of the sugar when delivered. 1/ During the past few years

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1/ Polarization represents with a fair degree of accuracy the percentage of sucrose in the raw sugar. Impurities which lower the polarization are moisture, nonsucrose sugars, organic matter, and minerals. These are contained primarily in the molasses film surrounding the raw sugar. Polarization losses are caused by an increase in the moisture or by the chemical breakdown of the sugar.

producers have been concerned about decreases in weight and polarization of raw sugar between the time it is produced and its arrival at mainland ports. These changes resulted in an average cost to producers of slightly more than $36,000 per mill per year in 1953 and 1954, but somewhat less than this in 1955 (table 1). On the basis of complete data from 6 mills, this amounts to approximately a million-dollar loss per year for all mills in Puerto Rico. The smaller losses in 1955 were due in part to a shift from shipment of bagged sugar to shipment of bulk sugar. Storage losses were not included in computing losses in the shipments of bulk sugar, because the weight and polarization of the sugar were not measured until just before it was loaded on the ship.

Table 1.--Value of changes in weight and polarization of raw sugar in storage and shipment from selected mills in Puerto Rico to mainland ports, annually, 1953-55 1/

Year	Mills	Value of changes at selected mills		
		Loss at all mills	Average loss per mill	Range among mills
	Number	Dollars	Dollars	Dollars
1953	6	217,712	36,285	-18,113 to -79,555
1954	6	217,814	36,302	-9,986 to -95,477
1955	5	108,868	21,773	2/+653 to -47,104

1/ The average prices used each year in computing value were $6.28, $6.07, and $5.94, New York raw duty paid, in 1953, 1954, and 1955, respectively.
2/ The weight of 96°-equivalent sugar was less at one mill than at mainland ports.

The general belief throughout much of the Puerto Rican sugar industry is that losses of weight in raw sugar shipped to the United States, especially to northern ports, are excessive and that there is no gain in polarization on most shipments to offset the weight loss. The Puerto Rican sugar industry, therefore, requested that a study be made of the losses of raw sugar in storage and shipment.

Several factors might cause a change in the weight and polarization of raw sugar between the time it is produced on the island and the time it arrives at mainland ports. The sugar may absorb or lose moisture, which would change the weight and the polarization in opposite directions. Also, raw sugar under certain conditions may break down into invert sugars through the actions of bacteria, yeasts, and molds. The invert sugars do not crystallize in the refining process.

Sucrose inversion can cause an increase in weight by increasing the absorption of moisture, but it would probably have a greater effect on polarization than on weight. The invert sugars have both negative and positive effects on polarization, but the negative effect is greater, so that the net effect of deterioration is a loss of polarization. (The invert sugars are recovered during refining and are marketable as refiner's sirup, but their value in refiner's sirup is less than the value of the sucrose from which they are formed.)

It is possible for deterioration to cause a gain in polarization, if certain yeasts further break down the invert sugar that has a negative effect on polarization.

Other sources of weight loss are breakage of bags and spillage, and the method of recording weights from the rising-beam scale which Puerto Rican producers reported as being used in some mainland ports.

The method of handling raw sugar is essentially the same at all Puerto Rican mills. Most of the sugar is stored in warehouses at the mill until it is shipped to mainland ports, except at a few mills that have their own port facility. At these mills sugar moves directly from the warehouse to the ship without having to be moved by rail or truck. The installation of bulk storage and handling facilities at some of these ports makes it possible to move sugar directly from the warehouse to the ship by belt conveyor.

The usual size of a shipment of bagged raw sugar is from about 2,000 to 5,000 tons, but the size may vary from less than 1,000 tons to 12,000 tons. The usual shipment of bulk sugar is approximately 8,000 tons.

One buyer usually purchases a shipload of sugar to be unloaded at one port, although the shipload may contain lots from several producers of raw sugar. At the mainland ports the bags of sugar are unloaded, and usually 8 bags are weighed at a time.

METHOD AND SCOPE OF STUDY

Information for the study was obtained by mail questionnaires and personal interviews with managers of raw sugar mills. The data obtained included the weight and the polarization of the raw sugar at the mill and at the mainland ports, the method and date of shipment, and the mainland port of entry. Some information was obtained from 21 of the 28 active mills. Complete data were obtained on shipments from 6 mills in 1953 and 1954, and 5 mills in 1955 (table 2).

Sugar was shipped in bags from 5 of the mills in 1953 and 1954, and 3 of the mills in 1955. The tonnage shipped in bags was slightly over 60 percent of the total from the selected mills in 1953 and 1954, but only about 25 percent in 1955, the remaining 75 percent being shipped in bulk. This shift to shipping in bulk has occurred in the industry at a rapid rate in 1956 and 1957. It was estimated that in 1957 more than 80 percent of the raw sugar from Puerto Rico was shipped in bulk.

Table 2.--Production and shipment of raw sugar from all operating Puerto Rican mills and from selected mills, annually, 1953-55 1/

Year	All mills	Selected mills	Production at all mills	Shipments to United States mainland		
				All mills	Selected mills	Selected as percentage of all
	Number	Number	Tons	Tons	Tons	Percent
1953	28	6	1,149,373	964,764	267,631	28
1954	28	6	1,171,485	931,377	289,503	31
1955	27	5	1,134,116	927,645	228,318	25

1/ Manual of Sugar Statistics, Association of Sugar Producers of Puerto Rico, 1956. Figures given are short tons, 96° basis.

For bagged sugar, changes in weight and polarization between the time the sugar was produced and its arrival at mainland ports were computed. For bulk sugar, weight and polarization were measured at each mill when the sugar was shipped, and again when it reached the mainland; the difference between measurements at the mill and those at the mainland indicated shipping losses. The weight loss at each mill in each year was computed, as well as the total loss at all mills in each year.

The changes were studied in relation to factors that would most probably influence them. The weight loss at each mill in each year was compared to the polarization loss at each mill in each year, to determine the relationship of weight losses to polarization losses. The shipments were grouped according to the mainland port to which they were shipped, to determine the relationship of losses to the port of entry. They were grouped also by month of arrival at mainland ports, to determine the effect of storage on losses. Storage was considered from the season the sugar was produced to the time it arrived at the mainland port.

Since losses of weight and of polarization both contribute to a loss in value, the total effect of both of these on the net change in pure sugar content was expressed in terms of a loss of weight in a sugar of a standard quality of 96° polarization, which is called the 96°-equivalent weight. 2/ The

2/ Raw sugar is of varying sugar content, but is usually between 96° and 98° polarization. The 96°-equivalent weight loss is the actual loss in weight and polarization adjusted to a loss of sugar of 96° polarization. In the trade, raw sugar is often described in terms of 96°-equivalent sugar.

96°-equivalent weight of each shipment was computed at the mill and at the port, and the difference was calculated. The total difference for all shipments from each mill in each year was shown. The relationship of 96°-equivalent weight losses to port of entry and time in storage was determined. Comparison of the change in the 96°-equivalent weight with the actual changes in weight and polarization of sugar gives information on the reasons for losses in storage and shipment; it also gives a measure of the combined effects of changes in weight and polarization on total losses of sugar.

An analysis of variance of weight and polarization losses was made to test the statistical significance of the difference in losses between northern and southern ports, and between shipments arriving at mainland ports before and after July 1 of a given year. The shipments were grouped before and after July 1 to show the effect of storage on losses. The analysis of variance covered different groups of mills, as well as some of the mills from which the percentage weight losses were computed. It was not possible to cover the same mills in all 3 years, because of lack of data. It was possible, however, to include in the analysis of variance other mills from which there was not sufficient information to compute both the percentage weight losses and the polarization losses. In the analysis of variance, the differences between shipments in average weight per bag and polarization of the sugar when it arrives at mainland ports were analyzed, and the differences that occurred between northern and southern ports and between periods of shipment were tested statistically to determine their significance. It was assumed that the average weight per bag and the average polarization would not vary greatly between shipments from an individual mill. An analysis of variance was also made of percentage weight losses.

METHODS OF MEASURING WEIGHT AND POLARIZATION OF BAGGED RAW SUGAR

At the Mill

The bags of raw sugar were weighed when they were filled at the mill, and the weight of an individual shipment was computed by the number of bags loaded. The weight per bag of sugar used in computing the weight of a shipment was either the average weight of the bags when they were filled or, when this was not available, a standard weight of 250 pounds, even though at some mills there was evidence that the bags were slightly heavier. Insular law requires that the weight of bags be recorded at the time the sugar is bagged.

The accuracy attained by using an average weight of bags of sugar in computing the weight of an individual shipment depends on the extent to which the weight of individual bags varies from the average. The greater the variation in bag weight, the greater the possible variation of the computed weight from the actual weight of the shipments. When all shipments are totaled, however, the variations in the computed weight from the actual weight will tend to cancel each other, so that the total computed weight of all shipments is a reasonably accurate measure of the weight of the sugar when it is produced.

The weight of bags is controlled by an automatic weighing device that also records the weight on a tape. It was reported at 1 mill that variation in weight between bags was negligible. The accuracy of the scales is also watched carefully at the mills. At 1 mill it was reported that the scales were checked every 2 hours with standard weights.

The mill polarization is an average of the polarization tests that are made when the sugar is produced. Although polarization tests are not made with the same frequency at all the mills, the methods of drawing the samples and determining the polarization are essentially the same. The usual method is to take a sample from each bag produced, and make a test of a composite of these samples. At one of the mills studied, 100 of the samples were mixed and a polarization test was made of the composite. This resulted in a test on each 12.5 tons produced. At another mill, 300 samples were mixed to form a composite, which resulted in a test on every 37.5 tons produced.

At Mainland Ports

The weight and polarization of each shipment of sugar are measured at the mainland ports. The same method of weighing is not used at all ports. The rising-beam scale used at some of the northern ports is calibrated at 4-pound intervals, and the beam usually indicates a weight somewhere within this interval. The lower value of the interval, however, is always the weight recorded. The recorded weight, therefore, is always lower than the actual weight, and may be as much as 4 pounds lower. The recorded weight would thus be expected to average approximately 2 pounds less than the actual weight. Usually 8 bags are weighed at a time. With a 2-pound loss on an 8-bag lot, the recorded weight of a shipment would be one-tenth of 1 percent less than the actual weight.

At the mainland ports, 3 polarization tests are made of each sample. One of these is made by the chemist representing the seller, 1 by the chemist representing the buyer, and 1 by the New York Sugar Trade Laboratory. The average of the nearest 2 polarizations becomes the final polarization of the sample. This method tends to minimize the effect of any extreme readings on the final polarization that is recorded.

Adjustment of Mill Polarization for Temperature

Of the sources of error in analysis for polarization, temperature is the one that is most likely to be significant in tropical climates. The saccharimeter is standardized for correct readings at 20° C., which is lower than the usual temperature in Puerto Rico. Since the polarization at 20° C. was available at only one of the sample mills, it was necessary to make corrections for temperature at the other mills, to make polarization at the mill comparable with polarizations at mainland ports.

The effect of an increase in temperature is a decrease in the saccharimeter reading. An approximately correct measure can be obtained on sugar above 96° polarization in temperature ranges of 20° C. to 30° C. by adding 0.03 degree of polarization for each degree of temperature above 20° C. Data were not available for temperatures in the laboratory, or for temperature of the sugar when the polarization tests were made at the mill. The published weather temperatures are averages of the maximum and minimum temperatures during each day, which may vary from the temperature in the laboratory. The polarization of the shipments at the selected mills was therefore corrected according to the temperature adjustments made at 1 mill. At this mill the correction to the 20° C. standard approximated 0.30 sugar degree in both 1953 and 1954, and on this basis the polarization at the other 5 mills was increased 0.30 sugar degree. 3/

LOSSES OF WEIGHT AND POLARIZATION IN BAGGED RAW SUGAR

Among all the mills, the range of weight losses was about the same as that of polarization losses. The weight losses ranged from 0.26 percent at mill B in 1954 to 0.99 percent at mill A in 1954, or 0.73 percent (fig. 1). The polarization losses ranged from 0.10° at mill A in 1954 to 0.88° at mill C in 1953, or a range of 0.78°. Weight losses at the mill having the greatest loss were almost 4 times greater than at the mill having the smallest loss. Polarization losses at 1 mill were almost 9 times greater than at another. The weight losses ranged from approximately one-half pound to 2 pounds per bag (fig. 2).

The different ways of computing weight of shipments at different mills are considered in analyzing variations in weight losses between mills. The polarization at each mill is an average of the tests made at the time the sugar was produced; this would not account for any of the variation in polarization losses between mills since the same method is used at all mills. At mills A and E, the average weight of the bags at the time of production was multiplied by the number of bags shipped to find the weight of the shipment. At mills B, C, and D, the weight was obtained by multiplying the number of bags loaded by a standard weight of 250 pounds. The loss in weight tended to be somewhat greater at mills A and E. This indicates that bags were slightly heavier than 250 pounds.

Different methods of calculating the weight of a shipment would not account, however, for the large variations between mills in weight and polarization losses. A certain amount of the variation in losses would be due to

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3/ Inaccuracies other than those due to temperature obviously may result from imperfect laboratory techniques and equipment. Authorities in the field state that these errors should not exceed +0.12 sugar degree in careful work. (See G. L. Spencer and G. P. Meade, Cane Sugar Handbook, 8th Ed., p. 397, 1945.) Since these errors may occur at either the mill or the mainland laboratory, they probably did not influence the results found in this study.

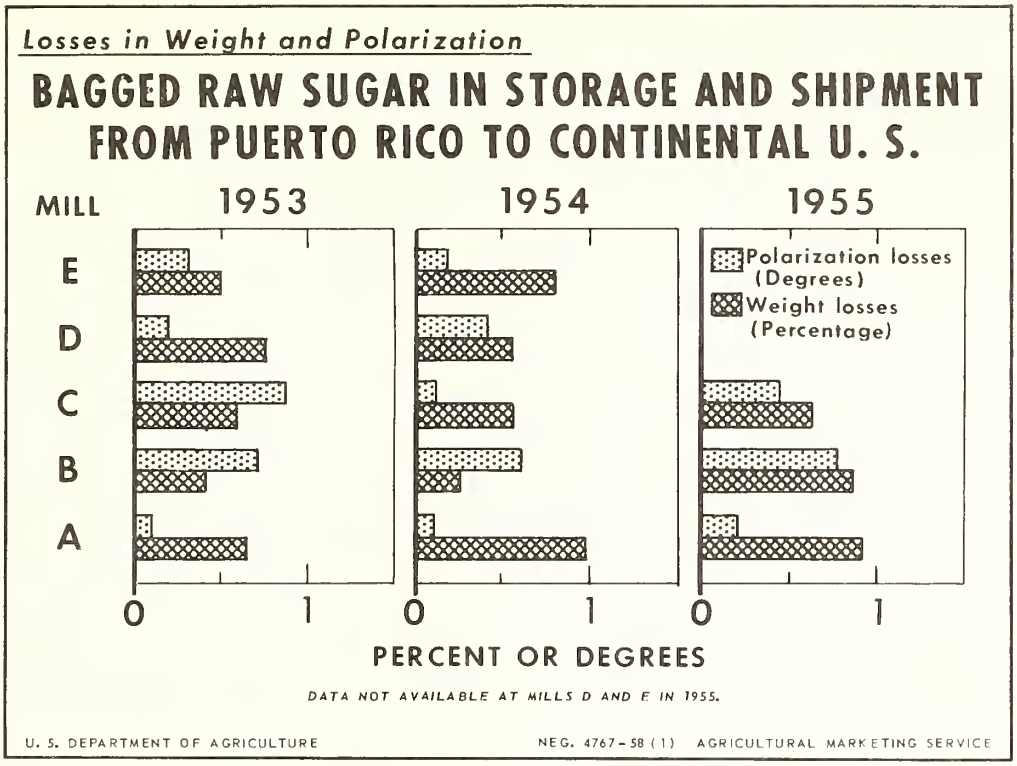

Figure 1

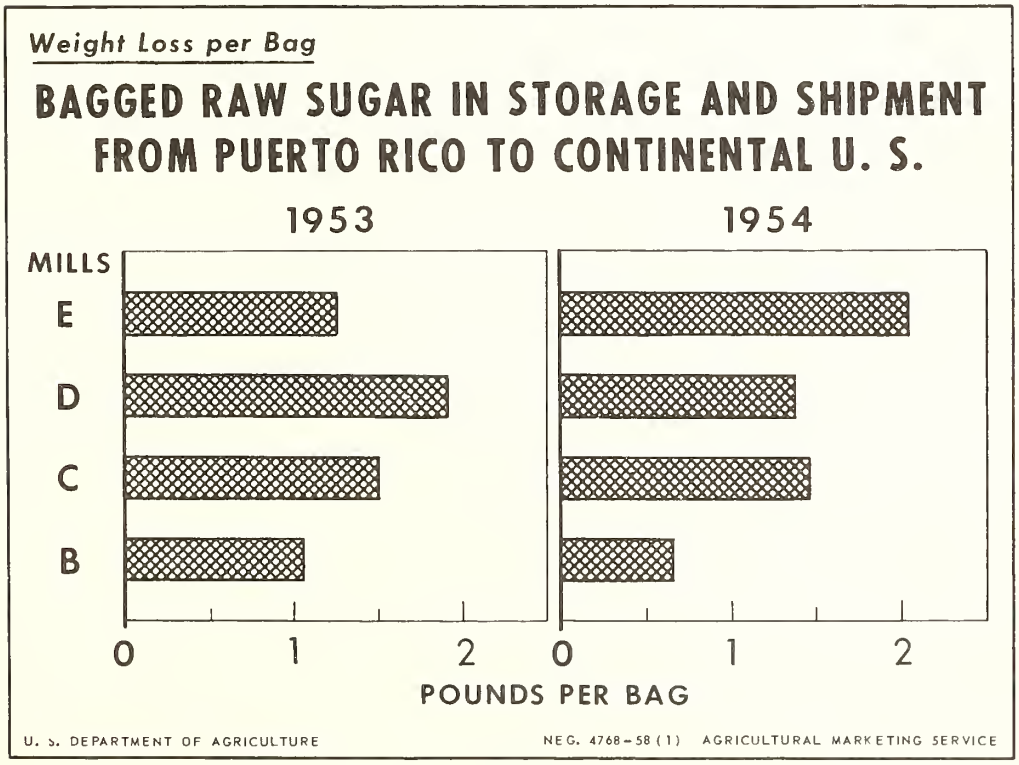

Figure 2

differences in qualities of sugar produced at the different mills. The handling and shipping procedures, although essentially the same at all mills, may result in variations in losses because of the greater care taken at some mills than others. The climate, which varies between the northern and the southern parts of the island and between the coastal and inland parts, also influences the storage losses.

Elsewhere in this report, other factors are shown to contribute materially to variations in losses between mills. These factors include the length of time in storage and the ports to which the sugar is shipped.

The percentage weight losses at all mills were greater than the average polarization losses (tables 3 and 4). In computing the average, the losses were weighted according to the tons shipped from each mill. The weight losses increased each year from 1953 to 1955. Polarization losses were about the same in 1953 and 1955, but slightly less in 1954.

Table 3.--Losses in weight of bagged raw sugar in storage and shipment between Puerto Rican mills and mainland ports, annually, 1953-1955 1/

Year	Actual weight				Weight loss, 96° basis	
	At mill	At port	Weight loss			
	Tons	Tons	Tons	Percent	Tons	Percent
1953	169,829	168,830	999	0.59	1,587	0.92
1954	173,459	172,193	1,266	.73	1,711	.97
1955	60,649	60,143	506	.83	786	1.27

1/ Based on shipments from 5 mills in 1953 and 1954, and 3 mills in 1955, short tons.

Table 4.--Losses of polarization of bagged raw sugar in storage and shipment from Puerto Rican mills to mainland ports, annually, 1953-1955 1/

Year	Polarization 2/		
	At mills	At port	Loss
	Degrees	Degrees	Degrees
1953	97.46	97.03	0.43
1954	97.88	97.59	.29
1955	97.83	97.39	.44

1/ Based on shipments from 5 mills in 1953 and 1954 and 3 mills in 1955.
2/ Average of shipments from each mill.

From information available, the specific weight loss from each of the several sources cannot be found, although certain estimates can be made. The weight loss due to bag breakage would probably be small since an attempt is made to recover all this sugar and credit it to the seller's account. For 1 mill, the normal bag breakage in storage and in transit to the ship was estimated to be about 1 bag in 400, or one-fourth of 1 percent. Even if all this sugar were lost, it would not account for nearly all the weight loss. The weight loss due to method of weighing in some ports theoretically would amount to one-tenth of 1 percent. This is discussed in more detail later. Weight changes due to moisture changes cannot be estimated with any reliability.

There is a tendency for the polarization losses to decrease as the weight losses increase (fig. 3). This indicates that the mills with the greater weight losses probably have greater moisture losses.

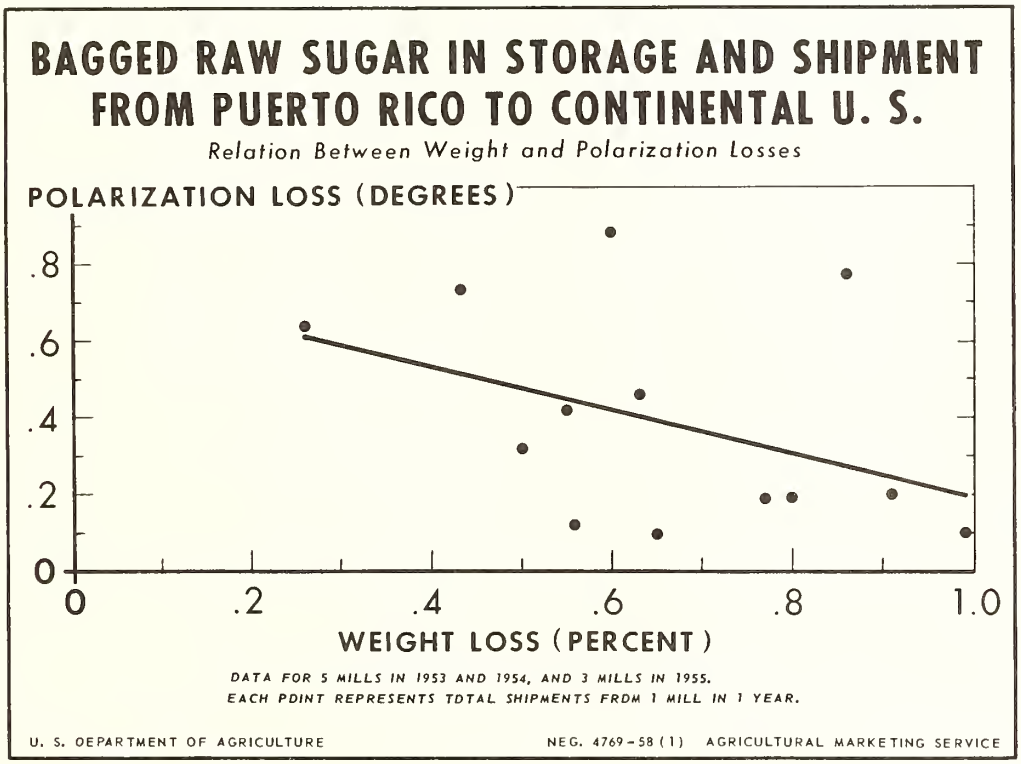

Figure 3

Weight losses due to moisture losses would be accompanied by proportionate polarization gains. Since the sugar is weighed while still warm and moist and the polarization test is made at the time the sugar is produced, a certain amount of weight loss and polarization gain would be expected. It is evident, however, that factors other than changes in moisture are present since there are both weight and polarization losses.

Weight Losses of 96°-Equivalent Sugar

Since there were both weight losses and polarization losses in the raw sugar in storage and shipment, a way was needed to express the total effects of these changes on the actual loss of sugar. On a few shipments there was a gain of polarization that partially offset weight losses, but on most of the shipments there was a loss of polarization. The net effects of the weight and polarization changes were expressed in terms of the 96°-equivalent weight loss, since raw sugar is priced on the basis of 96° sugar, with an increment or deduction in price for each degree or fraction thereof over or under 96°. In computing the 96°-equivalent weight loss of sugar, the weight of each shipment at the mill and at the port was multiplied by the polarization at the port. This gave the weight of the shipment on a 100° basis, which is taken to be 100 percent sugar. The 100° sugar was then adjusted to a 96° basis and the difference of the 96° sugar at the mill and at the port was computed. To adjust 100° sugar to 96° sugar, the 100° sugar is multiplied by a constant factor (1.04167) which is the percentage that 100 is of 96.

The 96°-equivalent weight losses at all mills were greater than the actual weight losses (table 3), because of a loss of polarization, and also because the actual weight loss is of sugar which is higher in polarization than 96°. There was considerable range of weight losses among the mills. The 96° losses varied from 0.68 percent at mill C in 1954 to 1.58 percent at mill B in 1955 (fig. 4). This was a range of nine-tenths of 1 percent.

The weight losses of 96°-equivalent sugar per bag shipped for most mills was between 2 and 3 pounds, but at 1 mill the difference was slightly over $3\frac{1}{2}$ pounds per bag (fig. 5).

Relationship of Losses to Port of Entry

A frequent complaint, that weight losses are greater at northern ports than at southern ports, was substantiated by data from 3 mills. Weight losses were about the same at all northern ports but Boston; there the losses were smaller than at other northern ports. However, only small quantities of sugar were shipped to Boston from the 3 mills studied, and these shipments may not be representative of all shipments to this port. At New Orleans the actual weight losses were about two-tenths of 1 percent less than at northern ports. At Savannah the weight losses were about three-tenths of 1 percent less than at the northern ports, and at Galveston they were about one-half of 1 percent less (tables 5 and 6).

The polarization losses were approximately the same at the ports of Philadelphia, Baltimore, New Orleans, and Galveston. Polarization losses were considerably greater at Boston than the other ports, but were considerably less at Savannah and New York.

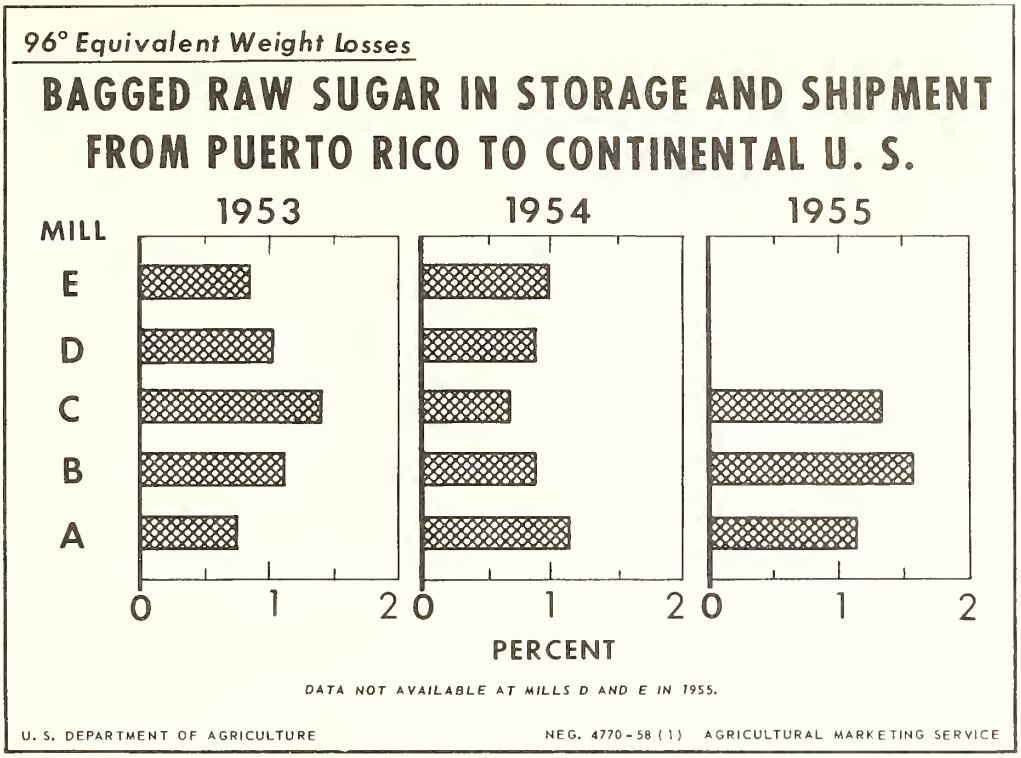

Figure 4

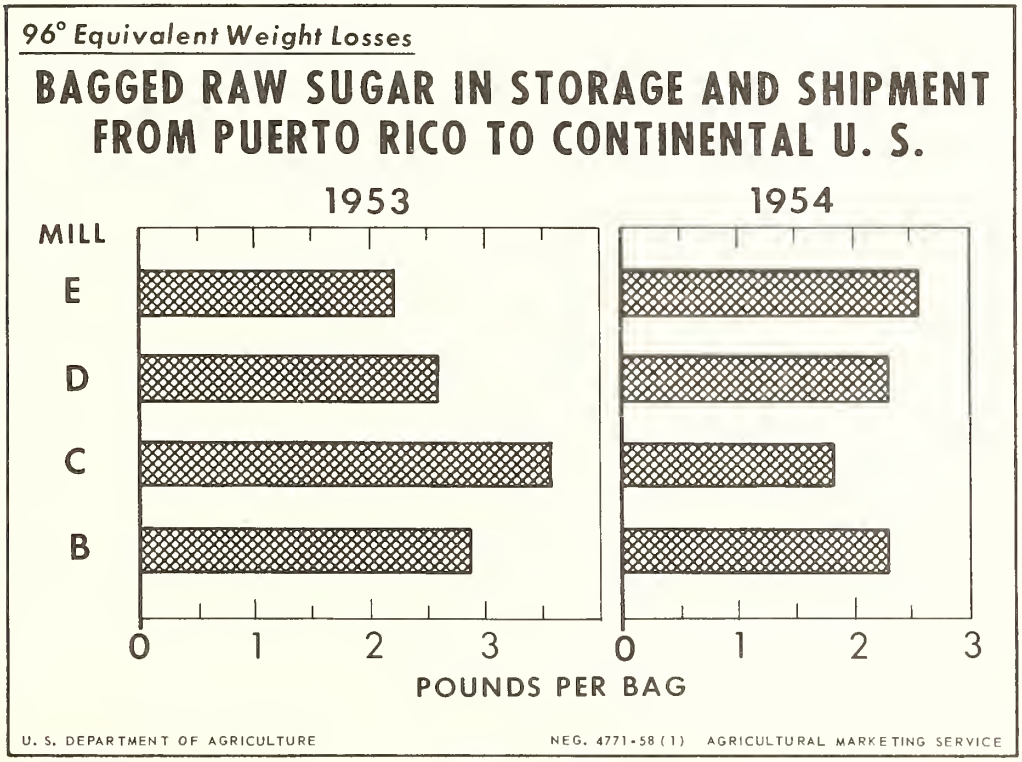

Figure 5

Table 5.--Losses of weight in bagged raw sugar in storage and shipment from 3 Puerto Rican mills to mainland ports, 1953 and 1954 production 1/

Port	Actual weight				Weight loss, 96° basis	
	At mill	At port	Weight loss			
	Tons	Tons	Tons	Percent	Tons	Percent
New York	118,275	117,356	919	0.78	1,196	0.99
Philadelphia	86,833	86,222	611	.70	820	.93
Baltimore	39,064	38,774	290	.74	426	1.07
Boston	2,674	2,663	11	.41	21	.77
New Orleans	16,625	16,532	93	.56	144	.85
Savannah	9,827	9,783	44	.45	58	.58
Galveston	15,720	15,677	43	.27	71	.44
Total	289,018	287,007	2,011	.70	2,736	.93

1/ Short tons.

Table 6.--Losses of polarization in bagged raw sugar in storage and shipment from 3 Puerto Rican mills to mainland ports, 1953 and 1954 production

Port	Polarization 1/		
	At mill	At port	Change
	Degrees	Degrees	Degrees
New York	97.81	97.64	-0.17
Philadelphia	97.66	97.42	-.24
Baltimore	97.69	97.41	-.28
Boston	97.64	97.16	-.48
New Orleans	97.39	97.15	-.24
Savannah	97.76	97.62	-.14
Galveston	97.71	97.49	-.21
Total	97.71	97.49	-.22

1/ Average of shipments.

The losses of 96°-equivalent weight were also greater at New York, Philadelphia, and Baltimore. The 96°-equivalent weight losses at Boston were less than at other northern ports and less than at New Orleans. The 96°-equivalent weight losses were substantially less at Savannah and Galveston than at all other ports.

Further statistical analysis indicated that there was a significant difference in weight losses between northern and southern ports (see appendix, tables 13 and 14), but that there was no significant difference in polarization losses between northern and southern ports.

With the small differences in time required for ships to sail from Puerto Rico to the various mainland ports, it is unlikely that climate in transit would have appreciably different effects on the sugar between northern and southern ports. It is significant that only weight losses vary appreciably between northern and southern ports, and not polarization losses. If the greater weight losses at northern ports were due to greater moisture losses, a smaller polarization loss or a polarization gain on these shipments would compensate for the weight losses, and the 96°-equivalent weight losses would be about the same at northern ports as at southern ports. The polarization losses were smaller at New York than at southern ports, but the losses of 96°-equivalent sugar were greater.

The use of the rising-beam scale could be a partial explanation of the greater loss of weight at northern ports, but it could not account for all losses.

Relationship of Losses to Time in Storage

Most of the sugar is placed in storage at the mill for shipment later in the year, although some moves directly to the ship after it is produced. The sugar which is moved directly to the ship would not be subject to the storage losses. Time in storage is counted from the time the sugar is produced, which is largely from February to May, until it arrives at mainland ports.

Weight losses were high in January and February, but dropped sharply in March. They were about the same for shipments arriving from March to October, but increased in November and December. Weight losses of sugar that was carried over from one production year and shipped in January and February of the following year were greater than for that shipped at any other period (tables 7 and 8).

Polarization losses increased gradually from January to June (the production season), increased sharply in July and August, and decreased slightly during the rest of the year. These changes indicate that sugar reaches an equilibrium with the atmosphere soon after it is produced, and remains fairly stable during the rest of the storage period.

An analysis of variance of shipments from one group of mills showed no statistically significant difference between losses of weight or polarization in sugar that arrived at mainland ports before July 1 and losses in sugar that arrived after July 1 (see appendix, tables 14 and 15). Weight losses in shipments by a different group of mills were significantly greater after July 1 (appendix, table 13).

Table 7.--Losses of weight in bagged raw sugar in storage and shipment from 5 Puerto Rican mills to mainland ports, by month of arrival at mainland ports, 1953 and 1954 production 1/

Month of arrival, 1953 and 1954	Actual weight				Weight loss, 96° basis	
	At mill	At port	Weight loss			
	Tons	Tons	Tons	Percent	Tons	Percent
Jan.-Feb.	11,000	10,912	88	0.80	98	0.87
Mar.-Apr.	82,634	82,135	499	.60	680	.81
May-June	37,578	37,347	231	.62	333	.87
July-Aug.	52,209	51,916	293	.56	495	.93
Sept.-Oct.	75,628	75,160	468	.62	726	.94
Nov.-Dec.	61,895	61,406	489	.79	717	1.14
Jan.-Feb. 2/	22,344	22,146	198	.89	250	1.08
Total	343,288	341,022	2,266	.66	3,299	.94

1/ Short tons.
2/ Arrival at mainland during 1954 and 1955 of carryover sugar.

Table 8.--Losses of polarization in bagged raw sugar in storage and shipment from 5 Puerto Rican mills to mainland ports, 1953 and 1954 production

Month of arrival, 1953 and 1954	Polarization 1/		
	At mill	At port	Change
	Degrees	Degrees	Degrees
Jan.-Feb.	97.72	97.64	-0.08
Mar.-Apr.	97.68	97.50	-.18
May-June	97.60	97.31	-.29
July-Aug.	97.65	97.11	-.54
Sept.-Oct.	97.71	97.19	-.52
Nov.-Dec.	97.68	97.25	-.43
Jan.-Feb. 2/	97.74	97.32	-.42
Average	97.67	97.31	-.36

1/ Average of shipments.
2/ Arrival at mainland during 1954 and 1955 of carryover sugar.

Losses of 96°-equivalent sugar increased with time in storage. The losses increased from March and April until November and December, but decreased slightly for carryover sugar in January and February.

Storage appeared to have a greater effect on weight losses than on polarization losses; the actual weight losses increased at a greater rate than the polarization losses after July and August (fig. 6). It was not possible from information available to learn why this was so. The time in storage may influence weight and polarization through changes in moisture, deterioration of the sugar, and breakage of bags. Moisture changes and deterioration are discussed in a later section.

Weight losses due to moisture losses during storage would be accompanied by polarization gains that would tend to compensate the weight losses. This would not affect the quantity of 96°-equivalent sugar. Absorption of moisture makes conditions favorable to deterioration, and deterioration increases the capacity of the sugar to absorb moisture, although deterioration is minimized in sugar of the quality produced today. The levulose formed during deterioration has a greater affinity for moisture than the other constituents of raw sugar.

Deterioration during storage would probably have a greater effect on polarization than it would on weight, although the losses found did not show this. The inversion of the sugar caused by deterioration would cause a loss of polarization, unless the deterioration proceeded to the stage of destroying the levulose and thus causing a gain in polarization. However, deterioration usually does not advance to this stage under commercial conditions.

Bag breakage, and weight losses resulting from it, may increase with the time in storage since sugar has a tendency to cake.

WEIGHT LOSSES AND POLARIZATION GAINS OF BULK SUGAR IN SHIPMENT

On shipments of bulk sugar, weight and polarization are measured after storage and just before shipment, and storage losses are not known. From 1953 to 1955 all bulk shipments were made to northern ports, so no comparisons could be made between northern and southern ports. For these reasons, data on bulk sugar cover only changes which occurred in handling and in shipping to northern ports, and are not directly comparable with data on bagged sugar.

Shipments of bulk sugar required 5 to 7 days to reach northern ports. During this time, plus the time required for loading and unloading, when the sugar was moved, stirred, and exposed to the air, some changes in weight and polarization might be expected. Variations in humidity and temperature between Puerto Rico and the United States mainland would cause some changes, depending on the time the sugar was exposed to the air. Because the warehouses for this bulk sugar were located at the ports, the sugar was probably exposed for only a short time.

Bulk sugar is weighed in larger lots than bagged sugar. As much as 10 tons of bulk sugar is weighed at a time, whereas approximately 1 ton of bagged sugar is weighed at a time. The accumulative error of weighing bulk sugar on the rising-beam scale would, therefore, be negligible.

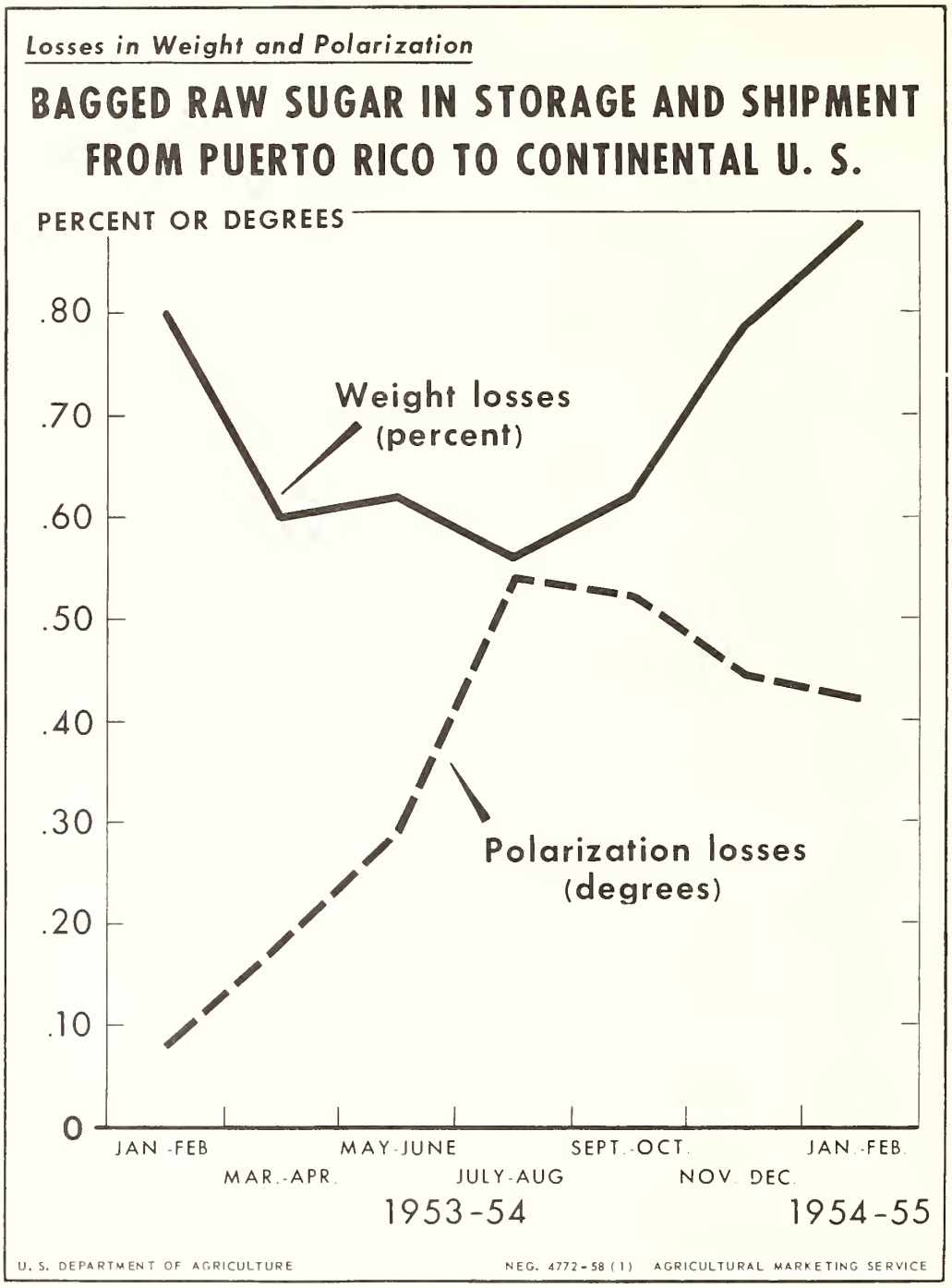
Losses in Weight and Polarization
BAGGED RAW SUGAR IN STORAGE AND SHIPMENT FROM PUERTO RICO TO CONTINENTAL U. S.
PERCENT OR DEGREES
.80
.70
.60
.50
.40
.30
.20
.10
0
Weight losses (percent)
Polarization losses (degrees)
JAN.-FEB.
MAR.-APR.
MAY-JUNE
JULY-AUG
SEPT.-OCT.
NOV. DEC.
JAN.-FEB.
1953-54
1954-55
U. S. DEPARTMENT OF AGRICULTURE
NEG. 4772-58 (1) AGRICULTURAL MARKETING SERVICE

Figure 6.

Weight losses were about the same each year, but polarization gains varied from year to year. The polarization gains compensated for most of the weight losses, so that the 96°-equivalent weight losses were only slightly more than one-tenth of 1 percent in 1953, and less than one-tenth of 1 percent in 1954 and 1955 (tables 9 and 10).

Table 9.--Losses of weight in bulk raw sugar in shipment from Puerto Rican mills to mainland ports, annually, 1953-1955

Year	Actual weight				Weight loss, 96° basis	
	At mill	At port	Weight loss			
	Tons	Tons	Tons	Percent	Tons	Percent
1953	94,658	94,397	261	0.28	144	0.15
1954	111,968	111,666	302	.27	82	.07
1955	164,047	163,622	425	.26	130	.08

Table 10.--Polarization gains of bulk raw sugar in shipment from Puerto Rican mills to mainland ports, annually, 1953-1955

Year	Polarization 1/		
	At mills	At port	Gain
	Degrees	Degrees	Degrees
1953	98.11	98.23	0.12
1954	97.98	98.18	.20
1955	97.99	98.17	.18

1/ Average of shipments.

No relationship was found between weight losses or polarization gains and month of shipment except for carryover sugar, which had greater weight losses (tables 11 and 12). Also, shipments of carryover sugar were the only ones in which there were losses of polarization.

CHANGES IN RAW SUGAR DUE TO CHEMICAL FACTORS

Many studies have been made of the physical and chemical changes occurring in raw sugar during storage. The findings of some of these studies are summarized to show the extent that various chemical and physical changes may have contributed to the weight and polarization losses described in this report.

Table 11.--Changes of weight in bulk raw sugar in shipments from Puerto Rican mills to mainland ports, by month of arrival at mainland ports, 1953 and 1954 production 1/

Month of arrival, 1953 and 1954	Actual weight				Change in weight, 96° basis	
	At mill	At port	Change			
	Tons	Tons	Tons	Percent	Tons	Percent
Jan.-Feb.	5,748	5,728	-20	-0.35	-4	-0.07
Mar.-Apr.	74,837	74,663	-174	-.23	-95	-.12
May-June	36,629	36,567	-62	-.17	+8	+.02
July-Aug.	30,923	30,815	-108	-.35	-69	-.22
Sept.-Oct.	32,579	32,518	-61	-.19	+12	+.03
Nov.-Dec.	16,205	16,108	-97	-.60	-26	-.16
Jan.-Feb. 2/	9,705	9,664	-41	-.42	-51	-.52
Total	206,626	206,063	-563	-.27	-226	-.11

1/ Short tons.
2/ Arrival at mainland during 1954 and 1955 of carryover sugar.

Table 12.--Polarization changes in bulk raw sugar in shipment from Puerto Rican mills to mainland ports, by month of arrival at mainland ports, 1953 and 1954 production

Month of arrival, 1953 and 1954	Polarization 1/		
	At mill	At port	Change
	Degrees	Degrees	Degrees
Jan.-Feb.	97.61	97.88	+0.27
Mar.-Apr.	98.14	98.24	+.10
May-June	98.06	98.24	+.18
July-Aug.	98.06	98.19	+.13
Sept.-Oct.	97.92	98.15	+.23
Nov.-Dec.	97.79	98.21	+.42
Jan.-Feb. 2/	98.28	98.19	-.09
Average	98.04	98.20	+.16

1/ Average of shipments.
2/ Arrival at mainland during 1954 and 1955 of carryover sugar.

Changes in Moisture Content

The organic nonsucrose constituents of raw sugar govern the moisture equilibrium point that is reached by the sugar and the surrounding air. Particles of bagacillo tend to hold moisture, but levulose affects absorption of moisture for more than any other impurities of raw sugar. Moisture absorption increases rapidly with increase in temperature and humidity when the levulose content is high, but there is little change in moisture content with increase in temperature and humidity when the levulose content is low. 4/

Studies have indicated that there is no absorption of moisture at 50 percent relative humidity, appreciable absorption in certain kinds of sugar at 75 percent relative humidity, and heavy absorption at 100 percent relative humidity. Over twice as much moisture is absorbed at 86° F. with 100 percent relative humidity as at 77° F. with 100 percent relative humidity. 5/ Some observers believe that 60 to 70 percent is the maximum safe humidity, but this is dependent on the "safety factor." This is the relationship of moisture to the nonsucrose material; it is sometimes expressed as a ratio, moisture/(100 - polarization). Some researchers in sugar have set the limit of the safety factor at 0.333, which means that moisture must not exceed one-third of the nonsucrose content. Others set the limit at 0.250 or less.

In a well-constructed warehouse that is kept closed, the moisture content of the air soon reaches an equilibrium with the sugars present, and no further gain or loss of moisture occurs (see footnote 5). In Cuba, well-made sugar has been kept in closed warehouses for 2 years with no loss in test. 6/ In the vicinity of New Orleans, raw sugar has been kept without change of weight or test for 9 months by keeping relative humidity below 75 percent. When the humidity rose above 75 percent, the temperature was raised to lower the humidity. The same sugar lost 0.8 percent in weight and 4° in polarization in a warehouse without humidity control. 7/

It is necessary to produce sugar of high quality and store it carefully to control moisture absorption in Puerto Rico, since the climate is generally favorable to the absorption of moisture and controlling moisture absorption is one way of controlling deterioration. The average temperature is 80° during the summer and 75° during the winter. The relative humidity usually exceeds 75 percent throughout the 24-hour day, and is usually higher on the northern

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4/ Spencer, G. L., and Meade, G. P. Cane Sugar Handbook. 8th ed., p. 273. New York, 1945.

5/ Keller, A. G., Factors Affecting the Keeping Qualities of Raw Sugar. Sugar Bul., vol. 17, No. 24, pp. 5-7. 1939.

6/ Spencer, G. L., and Meade, G. P. Cane Sugar Handbook. 8th ed., p. 274. New York, 1945.

7/ Scott, M. D. Experiments Conducted by the American Sugar Refining Company on the Keeping Qualities of Raw Sugar. Sugar Journ. vol. 2, No. 5. October 1939.

part of the island than the southern part. 8/ Few warehouses in Puerto Rico, and none of the mills studied, have facilities to control humidity.

Deterioration in Storage and Shipment

The deterioration of raw sugar in storage has received much attention, and the literature on it is voluminous. Vast improvements have been made in warehousing and in handling of raw sugar, but the greatest improvement has been in the manufacture of sugar that more closely conforms to the approved concept of the factor of safety. Since this study showed certain losses in weight and polarization which indicated deterioration in storage, it seems well to mention the general nature, effects, and control of this problem.

Deterioration of sugar in storage is brought about through the action of bacteria, yeasts, and mold. The relationship between moisture and the non-sucrose content is the determining factor in controlling the action of micro-organisms and sugar deterioration. Micro-organisms that cause deterioration cannot easily develop in concentrated molasses, but if the level of contamination reaches a certain point, controlling the moisture relationship is ineffective in controlling deterioration. The safety factor varies, therefore, according to the number of species of micro-organisms present.

As a result of deterioration, sucrose combines with water and is converted into a mixture of equal parts of dextrose and levulose, which is called invert sugar. Invert sugar, besides being noncrystalline, has an effect on polarization, and the true sucrose value of the sugar cannot be found by the single polarization that is used in commercial analysis. In the optical method of finding the polarization of a sample of sugar, the angle of rotation of plane-polarized light is measured by a saccharimeter equipped with a scale to show the percentage of sucrose in the sample being tested.

All sugar has the property of rotating a beam of plane-polarized light; however, the extent and direction of rotation differs with the different types of sugar. Dextrose and sucrose both rotate the plane in a clockwise direction when viewed through the saccharimeter, whereas levulose rotates the plane in a counterclockwise direction. When dextrose and levulose are present in equal quantities, as they are in invert sugar, the effect of the levulose is greater than the dextrose, hence the net effect is a lower polarization than there would be if the invert sugars were not present. The percentage of sucrose will be higher than the polarization by about one-third of the percentage of invert sugar present. In some sugars, however, the polarization may be higher than the percentage of sucrose as a result of sucrose inversion. This happens when levulose is further destroyed by the action of certain yeasts.

8/ Yearbook of Agriculture. Climate and Man. U. S. Dept. Agr., pp. 1, 227. 1941.

NEED FOR FURTHER RESEARCH

Detailed study is needed to show how much each of the various factors contributes to losses in Puerto Rican raw sugar, and why there are variations in losses between mills. Quantities of sugar produced and stored at several mills located in different sections of the island should be drawn as samples and studied under actual storage conditions. The physical losses in handling and shipping should be ascertained. The raw sugar should be weighed and a polarization test and further chemical analysis made when the sugar is produced, periodically during storage, when the sugar is shipped, and when it arrives in mainland ports, to learn the exact nature of the losses and when they occur.

Developments in the Puerto Rican sugar industry make it necessary to study losses in storing and handling bulk sugar. Further, a study of the sources and extent of losses should be accompanied by a study of the costs of equipment and practices necessary to reduce losses.

APPENDIX

An analysis of variance was made of percentage weight loss, weight per bag at mainland ports, and polarization of the sugar at mainland ports to test whether the differences in weight and polarization losses found between northern and southern ports and between periods of shipment were statistically significant. The analysis of percentage weight losses included shipments from one mill in 1953, 1954, and 1955, and shipments from another mill in 1954. No other mills made shipments in all of the classifications that were compared. The shipments were grouped into those going to the northern ports of Philadelphia, New York, Boston, and Baltimore, and those going to the southern ports of New Orleans, Galveston, and Savannah. The shipments going into each group of ports were then subdivided into shipments made before July 1 and shipments made after July 1.

The percentage weight losses were found to be greater in northern ports than southern ports, and greater after July in both groups of ports (table 13). The average percentage weight loss at northern ports was 0.8254, and at southern ports 0.4100. The difference was 0.4154. The average percentage weight loss before July 1 was 0.7528, and after July 1 it was 0.4826. The difference was 0.2702. The differences between northern and southern ports and between shipments before and after July 1 were statistically significant at the 1-percent level. Also, the tendency for percentage weight losses to change more in southern than in northern ports during the shipping season was statistically significant at the 1-percent level.

For shipments from another group of mills, the average weight of the bags of each shipment of sugar after they arrived at the mainland ports were compared between periods and between northern and southern ports. It was assumed that the bags of sugar all weighed approximately the same when produced, and that any differences in the weight found when they were weighed at mainland ports were due primarily either to conditions in the port to which they were shipped or to the time that the sugar was in storage. The analysis of average bag weight covered the shipments from 1 mill in 1953, 1 mill in 1954, and 2 mills in 1955.

The average weight per bag was 250.58 pounds in northern ports and 251.76 pounds in southern ports. The difference between ports was 1.18 pounds per bag. The average weight per bag before July 1 was 251.07 pounds, and after July 1 it was 251.27, a difference of 0.2 pound per bag. The difference between northern and southern ports was statistically significant at the 1-percent level.

The bags that were shipped to northern ports had lost more weight, but the difference between shipments before and after July 1 was small (table 14). The variance of the average weight per bag at mainland ports between mills was so great that the difference before and after July 1 was statistically inconclusive.

Table 13.--Weight loss of raw sugar shipped from mills in Puerto Rico to mainland ports, by northern and southern ports and by time of arrival, 1953-1955

Mills 1/	Weight loss at--				Average weight loss at all ports
	Northern ports		Southern ports		
	Before July 1	After July 1	Before July 1	After July 1	
	Percent	Percent	Percent	Percent	Percent
1	0.68	0.70	0.27	0.73	0.60
2	.81	1.26	.22	.90	.80
3	.84	1.03	.24	.64	.69
4	.76	.52	.04	.25	.39
Average ...	.77	.88	.19	.63	.62

1/ Numbers 1, 2, and 3 are the same mill in 1953, 1954, and 1955, respectively, and number 4 is a different mill in 1954.

Table 14.--Average weight of bags of raw sugar at mainland ports from Puerto Rico, by port and by time of arrival, 1953-1955

Mills 1/	Average weight per bag at--				Average weight per bag at all ports
	Northern ports		Southern ports		
	Before July 1	After July 1	Before July 1	After July 1	
	Pounds	Pounds	Pounds	Pounds	Pounds
1	253.66	254.28	255.37	254.91	254.55
2	248.11	248.69	249.89	249.39	249.71
3	249.28	249.33	250.87	249.36	251.40
4	250.08	251.17	251.27	253.06	249.02
Average ...	250.28	250.87	251.85	251.68	251.17

1/ Each item represents shipments from a different mill in a particular year between 1953 and 1955.

For 8 different mills, polarization of sugar shipped by 2 mills in 1953, 3 mills in 1954, and 6 mills in 1955 (table 15) was compared between northern and southern ports and before and after July 1. No significant difference in polarization of the sugar between periods of shipment or between northern and southern ports was found.

Table 15.--Average polarization of raw sugar at mainland ports from Puerto Rico, by northern and southern ports and by time of arrival, 1953-1955

Mills 1/	Average polarization at--				Average polarization at all ports
	Northern ports		Southern ports		
	Before July 1	After July 1	Before July 1	After July 1	
	Degrees	Degrees	Degrees	Degrees	Degrees
1	97.93	97.51	97.59	97.67	97.67
2	97.47	97.56	97.25	97.58	97.46
3	97.93	97.95	98.00	97.99	97.97
4	97.09	96.87	97.04	96.94	96.99
5	97.36	97.28	97.53	97.70	97.47
6	97.58	97.41	97.51	97.64	97.54
7	97.50	97.43	97.56	97.36	97.46
8	97.35	97.59	97.41	97.47	97.45
9	97.11	97.59	97.43	97.09	97.31
10	97.93	97.86	98.00	97.98	97.94
11	97.81	97.56	97.91	97.68	97.74
Average..	97.55	97.51	97.57	97.55	97.54

1/ Eight different mills are represented in the table for particular years between 1953 and 1955.

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